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INFLUENCE OF GEOMETRICAL MAGNIFICATION ON COMPUTED TOMOGRAPHY DIMENSIONAL MEASUREMENTS

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Abstract

Computed tomography is a widely used method in the field of dimensional measurements. It is a non-contact, non-destructive measurement method that enables insight into both external and internal geometry of measured part which allows measurement of characteristics otherwise unreachable with tactile measurement methods. The biggest problem with computed tomography measurements is lack of metrological traceability. Because of the fact that a lot of parameters influence the whole measurement system, measurement uncertainty is still not evaluated. In this paper, influence of one of the influencing parameters, geometrical magnification, on results of dimensional and geometrical measurement characteristics was observed. Besides experimental research, simulations of computed tomography scanning were done. Measurement results obtained from both scanned and simulated models were compared and observed with regard to reference values. Results obtained from scanned model showed predictable behaviour compared to results obtained from simulated model.

Keywords: Computed tomography; dimensional measurements; influence parameters; geometrical magnification.

1. Introduction

Computed tomography – CT is a new method used in the field of dimensional measurements. It is a non-contact, non-destructive measurement method that enables insight into both external and internal geometry of measured part which allows measurement of characteristics otherwise unreachable with tactile measurement methods. Computed tomography uses X-ray for obtaining large number of 2D scans that arise during rotation of part for 360 degrees, which are later used for rendering real 3D model of measured part. Concerning the fact that this is a new dimensional measurement method with a large number of influencing parameters, measurement uncertainty is still unknown and metrological traceability is still not achieved [1-5]. With aim to assure metrological traceability, identification of all influencing parameters and their contribution to measurement uncertainty is necessary. In this paper influence of geometrical magnification on measurement results has been analyzed. Also, comparison of measured results obtained from real scanned model and simulated model was done. Experimental scanning was performed on CT device for dimensional measurements produced by Nikon, model XT H 225, while simulation of X-ray scanning were performed in software package 'aRTist – *trial* *version*' (analytical Radiographic Testing inspection simulation tool) by BAM (Federal Institute for Materials Research and Testing) [6-8].

Selected object for this analysis was cylinder made from aluminium, and the following dimensional characteristics were observed: inner and outer diameter and cylinder length, and geometrical characteristics: coaxiality and parallelism.

2. Usage of computed tomography in dimensional measurements

Computed tomography method is known for over 40 years when it was first implemented in field of medicine, and later from 1980s in field of material analysis [9]. Idea for applying computed tomography for dimensional measurements emerged at the beginning of 1990s when first dimensional measurement was done. Accuracy of obtained results was about 0.1 mm [10]. After that event, significant development of CT devices suitable for dimensional measurements has begun. First CT device for dimensional measurement was presented in 2005 on Control Fair in Sinsheim, Germany by producer Werth Messtechnik GmbH [11]. Today, computed tomography method is widely used in field of dimensional measurement, but a problem with lack of measurement uncertainty and connected to that, lack of metrological traceability is still present [12-14]. In order to achieve metrological traceability, it is necessary to assess measurement uncertainty of measured results. Parameters influencing the whole CT measurement process contribute to measurement uncertainty, so the first step in addressing measurement uncertainty is identification of all influencing parameters. Considering the fact that process of dimensional measurement with computed tomography consists from three separate sub-processes, influencing parameters can be divided into three sub-classes: parameters influencing scanning process, parameters influencing modelling process and parameters influencing measurement process. On the other hand, some authors [15-17] classified influencing parameters as: environmental parameters, hardware parameters, software parameters, object related parameters and influence of operator. Here, classification of parameters considers hardware parameters, software parameters and other parameters and it is given in Table 1.

Hardware influencing parameters	**Software influencing parameters**	**Other influencing parameters**
- X-ray source - Rotational table - X-ray sensor (detector)	- 3D reconstruction - Surface determination - Software correction of beam hardening, noise reduction and scattering	- Influence of measured part (dimensions, geometry, surface characteristics – roughness) - Environmental parameters (temperature, humidity, vibrations) - Influence of operator skills and measurement approach (choose of input parameters, object position, number of projection images...)

Table 1. Classification of CT system influencing parameters

One of the parameters related to operator is position of the measured part, and connected with that the parameter of geometrical magnification. Geometrical magnification (1) is defined as ratio between source-to-detector distance (*SD*) and source-to-object (*SO*) distance.

$$Geometrical\ magnification = \frac{SD}{SO} \quad (1)$$

By positioning the object closer to X-ray source, larger resolution can be achieved, but at the same time, picture of the scanned object results in less sharp edge projection with appearance of so called penumbra effect [15]. In standard CT systems, source-to-detector distance is constant, so geometrical magnification depends only on source-to-object distance. With increase of source-to-object distance, geometrical magnification decreases. Lower geometrical magnification means lower resolution, but enables scanning of the whole part, especially when large size objects are investigated. Influence of geometrical magnification on CT measurement results is significant, where deviations in results increase with increase of geometrical magnification [18-20]. In this paper object with simple geometry, aluminium cylinder has been investigated in order to obtain behaviour of results depending on geometrical magnification and define deviations in results obtained by scanning and simulations. Observed were three dimensional characteristics: outer diameter *D*, inner diameter *d* and length *l* and two geometrical characteristics: parallelism of top and bottom cylinder planes and coaxiality between outer and inner cylinders.

3. Experimental research

Experimental researches consist of:

- performance of CT scanning real part, data processing and measurement of reconstructed 3D model,
- performance of CT simulation, where the same scanning settings as in real scanning process were chosen.

3.1. CT measurements

CT scanning was performed on industrial CT device by Nikon, model XT H 225. Chosen scanning parameters are given in Table 2 and Table 3. With the fact that in this research influence of one parameter, geometrical magnification was investigated, other scanning parameters were kept constant. Table 2 presents scanning parameters set for all five cases while in Table 3 are given source-to-object distances and amounts of geometrical magnification according to (1).

Parameter	**Amount**
Voltage, kV	130
Current, µA	30
No.of projections	1000
Detector size, pixels	3192 x 2296
Pixel size, µm	127 x 127
X-ray spot size, µm	3.9

Table 2. Scanning parameters

Parameter	**Experiment No.**				
	1	**2**	**3**	**4**	**5**
Source-to-object distance, mm	200	300	400	500	600
Geometrical magnification	4.921	3.281	2.461	1.968	1.640

Table 3. Source-to-object distances

CT models of scanned parts were generated with usage of software package CT-Pro, and measurements were performed in software VGStudio Max 2.2. Chosen measurement strategy involved fitting simple geometry objects where both outer and inner diameters were fitted with cylinders, using Gaussian approach; length was measured as a distance between two planes; parallelism was observed as a geometrical measurand of two planes, and coaxiality was observed between outer and inner cylinders (Table 4).

Measurand	**Strategy**
Outer diameter, D, mm	Cylinder
Inner diameter, d, mm	Cylinder
Lenght, l, mm	Plane - Plane
Parallelism	Plane - Plane
Coaxiality	Cylinder - Cylinder

Table 4. Measuring strategy for CT measurements

3.2. CT simulations

CT simulations were conducted in software for radiographic testing named ‘aRTist’ (analytical Radiographic Testing inspection simulation tool), developed by *Bundesanstalt für Materialforschung und –prüfung*, BAM, Germany. For simulation of the CT process, modules aRTist image view and Ct scan were used. Program setups were the same as real setups and limitations of Nikon XT H 225 device. The same input scanning parameters as the one used for CT scanning of the real part, stated in Tables 2 and 3 were chosen. CAD model of cylinder made according to the actual reference values was simulated. Figure 1 presents drawing of simulated cylinder.

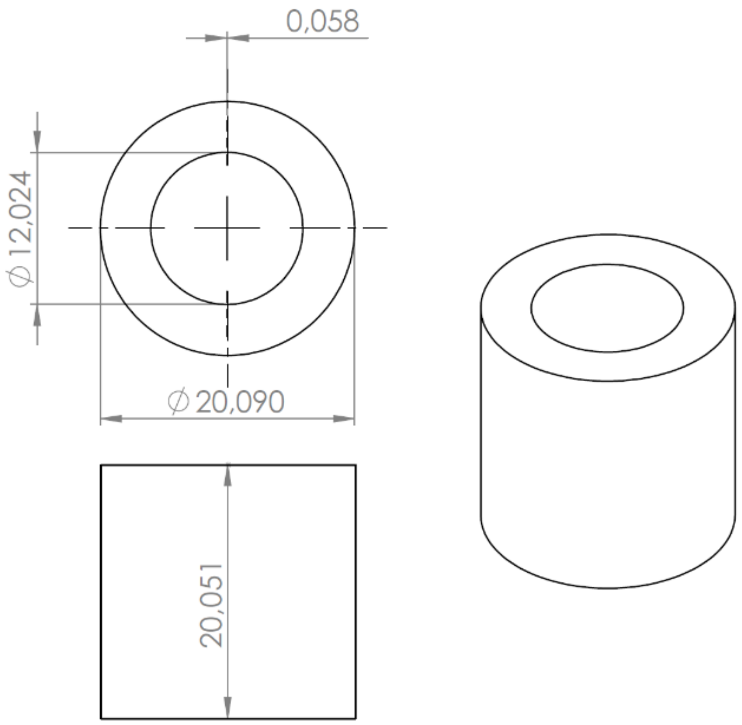

Figure 1. Drawing of cylinder with dimensions and model of cylinder

Models generated with usage of aRTist were also analyzed with software packages for measurements and data analysis VGStudio Max 2.2. The same measurement method was used for measurement performance on simulated models (Table 4.).

4. Results

Results are given graphically as deviations of experimentally obtained results of CT scanning from reference values and as deviations of results from simulation obtained scanned model and measured results from reference values. Deviations are given on the same graph.

Reference measurements were performed on coordinate machine Ferranti Merlin and measurements were done in software MODUS. The reproducibility was obtained by measuring the cylinder three times in different days during the period of two weeks. Table 5 presents measured results and related measurement uncertainties of dimensional and geometrical characteristics.

Measurand	**Measured results**	**Expanded measurement uncertainty *U*, *k* = 2, *P* = 95 % , µm**
Outer diameter, *D*, mm	20.098	4
Inner diameter, d, mm	12.017	4
Length, *l*, mm	20.063	4
Parallelism, mm	0.055	1
Coaxiality, mm	0.019	1

Table 5. Reference values

Results obtained from CT measurements for outer diameter presented in Figure 1 show almost linear fall in amount with increase of source-to-object distance. Deviations of measured results obtained in CT simulations show decline in value of cylinder outer diameter with increase of source-to-object distance until the amount of source-to-object distance reaches 400 mm. After that, the value of outer diameter starts to grow significantly. The best agreement between results obtained from CT measurements and CT simulations are in the source-to-object distance range 300-400 mm, which equals geometrical magnification range between 3.281 and 2.461.

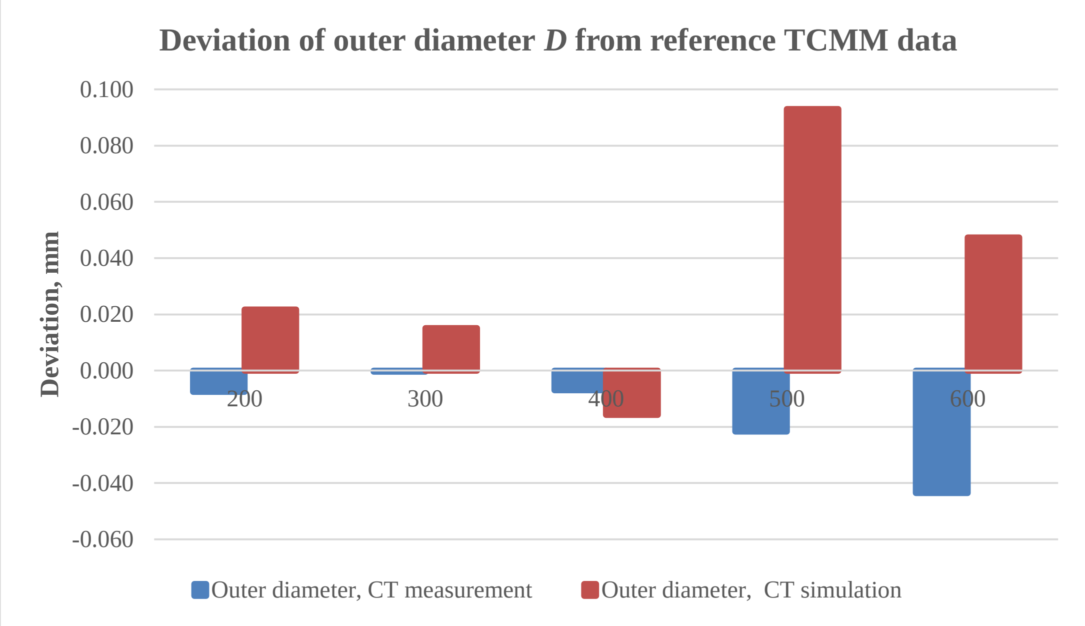

Figure 2. Deviation of outer diameter from reference values

Figure 3 shows deviations of cylinders inner diameter from reference values in dependence of source-to-object distance. Results obtained in CT measurements show increase of deviation in inner diameter with increasing source-to-object distance. Behaviour of simulated results shows significant decrease of deviation in inner diameter until the amount of source-to-object distance equals 400 mm and from 400 mm to 600 mm slight decline in results is observed.

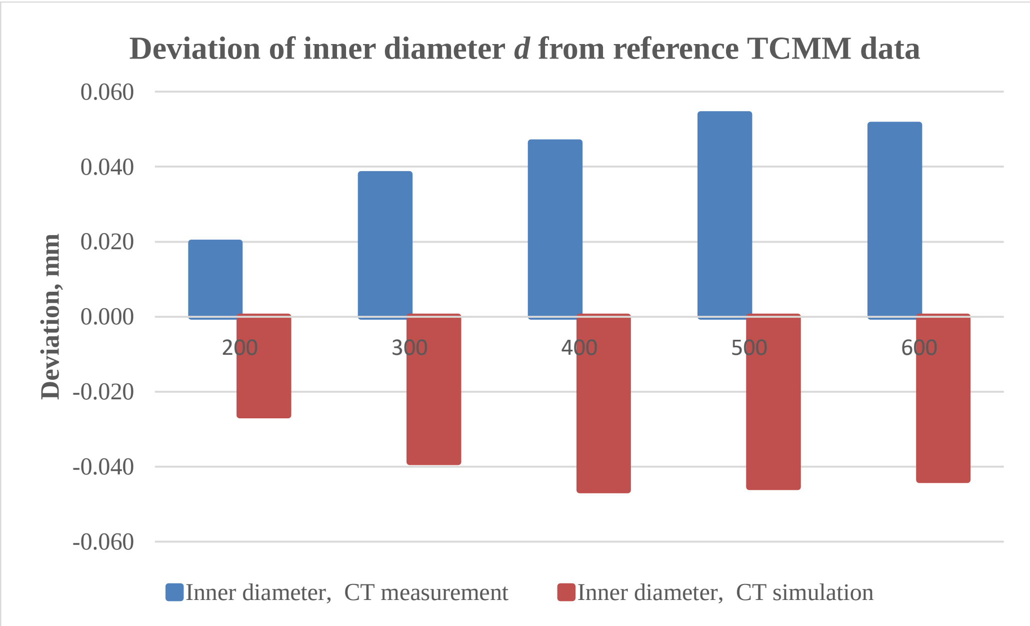

Figure 3. Deviation of inner diameter from reference values

In the Figure 4 an increase in deviation of cylinder length with increase of source-to-object distance from 200 mm to 400 mm distances, for results obtained by CT measurements, is visible. Maximal deviation between cylinder length and reference value is noted for distances from X-ray source in the range of 300 mm to 400 mm, while the best results are obtained when the object is as close as possible to X-ray source, but also in the case when object is the nearest to the detector. Simulated results on the other hand show the biggest deviation from reference value in case where the object is near the X-ray source. Measured and simulated results in dependence of geometrical magnification showed the biggest discrepancy in case of length measurements.

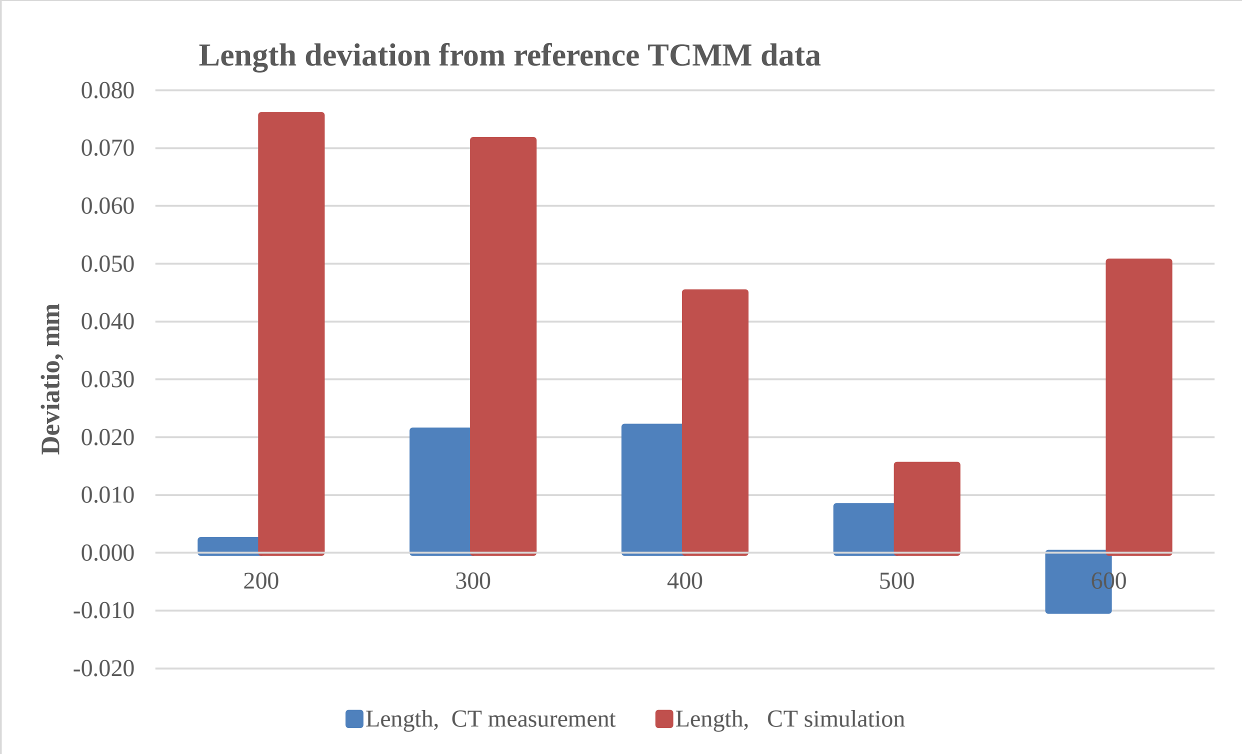

Figure 4. Length deviation from reference values

From geometrical characteristics, parallelism and coaxiality were observed. Results of parallelism obtained from CT measurements and the one obtained from CT simulations show equal behaviour with increase of source-to-object distance (Figure 5).

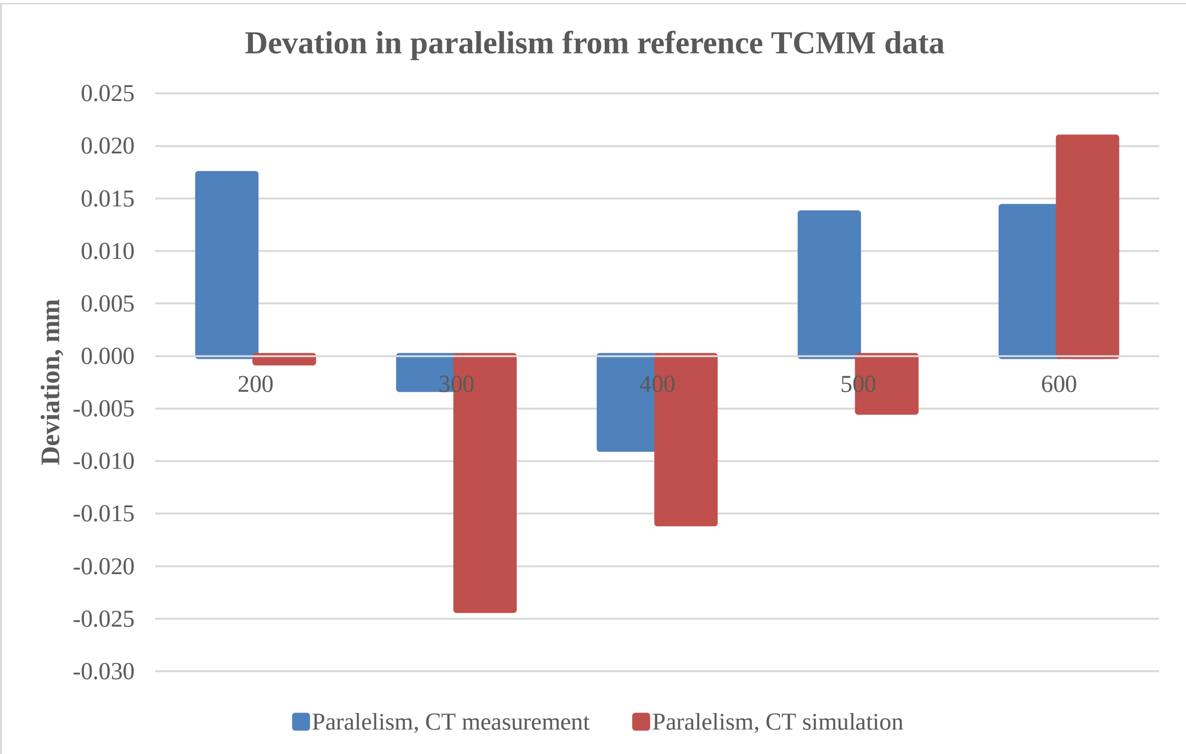

Figure 5. Deviation in parallelism from reference values

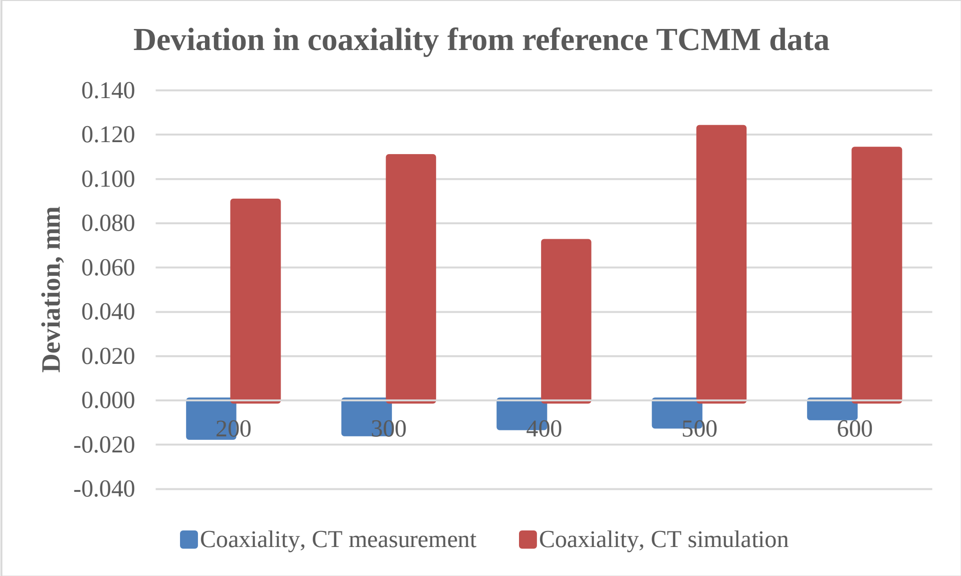

Figure 6. Deviation in coaxiality from reference values

Results of coaxiality (Figure 6.) obtained from CT measurement show invariance with increase of source-to-object distance. On the other hand, results obtained from CT simulations behave totally unpredictable.

5. Conclusion

In this research measurements of dimensional and geometrical characteristics were monitored. Dimensional characteristic of outer and inner diameter, as well as length of the aluminium cylinder were observed. Research included observation of influence parameter geometrical magnification on measurement results obtained with usage of computed tomography. Two approaches were conducted, first one included performance of experiment on CT device Nikon X TH 225 while second approach was simulation of CT scanning process by using simulation software for radiographic testing ‘aRTist’ (analytical Radiographic Testing inspection simulation tool), developed by *Bundesanstalt für Materialforschung und –prüfung*, BAM, Germany. Observed were deviations of measured characteristics from reference values obtained on coordinate tactile measurement machine. Obtained results showed significant deviations from reference values. General conclusion is that results obtained by CT scanning behave in predictable way, where results of outer diameter fall with decrease of geometrical magnification, while results of inner diameter rise with decrease of geometrical magnification parameter. Results obtained by CT simulation in case of outer diameter showed good agreement with reference values for source-to-object distance from 200 mm to 400 mm, while results in case of higher source-to-object distance showed unpredictable leap. The same unpredictable leap in results obtained by CT scanning occurs in length measurement for source-to-object distance from 500 mm and over. Observation of geometrical characteristics results depending on geometrical magnification showed, in case of parallelism similarities within results obtained by scanning and simulations. Obtained results deviate from reference values approximately 0.020 mm in absolute amount. On the other hand results of coaxiality obtained by CT scanning showed invariance on geometrical magnification change, while results obtained by CT simulation behave totally unpredictable and deviate from reference values for about 0.100 mm.

Further step in research in a field of computed tomography dimensional measurement and achievement of metrological traceability should include evaluation of components of measurement uncertainty with further aim to asses measurement uncertainty of results obtained with CT measurement method which is basis for achievement of metrological traceability.

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